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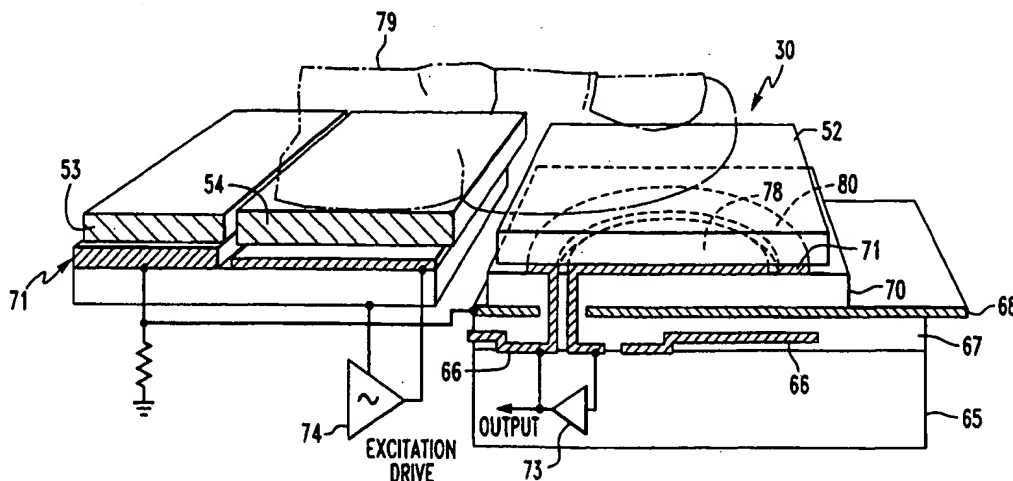
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## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT) -

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|--|--|---|--|
| (51) International Patent Classification <sup>6</sup> :<br><b>G06K 9/20, A61B 5/117</b>  |  | A1  | (11) International Publication Number: <b>WO 98/52146</b>        |
|  |  |   | (43) International Publication Date: 19 November 1998 (19.11.98) |
| (21) International Application Number: PCT/US98/09228<br>(22) International Filing Date: 6 May 1998 (06.05.98)<br>(30) Priority Data:<br>08/857,524          16 May 1997 (16.05.97)          US<br>(71) Applicant: HARRIS CORPORATION [US/US]; 1025 West Nasa Boulevard, Melbourne, FL 32919 (US).<br>(72) Inventors: SETLAK, Dale, R.; 3633 Sandy Crane Court, Melbourne, FL 32934 (US). GEBAUER, Dave; 7978 Timberlake Drive, West Melbourne, FL 32904 (US).<br>(74) Agent: NIYOGI, Bidyut, K.; Harris Corporation, International Patent Operations, 1025 West Nasa Boulevard, MS80, Melbourne, FL 32919 (US). |  | (81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, GW, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).<br><br>Published<br>With international search report. |  |

(54) Title: FINGERPRINT SENSOR HAVING FILTERING AND POWER CONSERVING FEATURES AND RELATED METHODS



## (57) Abstract

A fingerprint sensor includes an array of fingerprint sensing elements and associated active circuits and an impedance matrix filter connected to the active circuits for filtering the signals. The impedance matrix filter comprises a plurality of impedance elements with a respective impedance element connectable between each of the active circuit for each fingerprint sensing element and at least one other active circuit for an adjacent fingerprint sensing element. The impedance matrix filter includes a plurality of switches with a respective switch connected in series with each impedance element. The switches are selectively operated to determine ridge flow directions of the fingerprint image. The ridge flow directions are used to determine a core location of the fingerprint image. The switches are selectively operated to convert a gray scale fingerprint image to a binarized fingerprint image. Processing of the fingerprint image is carried out at the sensor and reduces additional downstream computational requirements.

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## FINGERPRINT SENSOR HAVING FILTERING AND POWER CONSERVING FEATURES AND RELATED METHODS

The present invention relates to the field of personal identification and verification, and, is particular, to the field of fingerprint sensing and processing.

Fingerprint sensing and matching is a reliable and widely used technique for personal identification or verification. In particular, a common approach to fingerprint identification involves scanning a sample fingerprint or an image thereof and storing the image and/or unique characteristics of the fingerprint image. The characteristics of a sample fingerprint may be compared to information for reference fingerprints already in a database to determine proper identification of a person, such as for verification purposes.

A typical electronic fingerprint sensor is based upon illuminating the finger surface using visible light, infrared light, or ultrasonic radiation. The reflected energy is captured with some form of camera, for example, and the resulting image is framed, digitized and stored as a static digital image. The specification of U.S. Patent No. 4,210,899 discloses an optical scanning fingerprint reader cooperating with a central processing station for a secure access application, such as admitting a person to a location or providing access to a computer terminal. The specification of U.S. Patent No. 4,525,859 discloses a video camera for capturing a fingerprint image and uses the minutiae of the fingerprints, that is, the branches and endings of the fingerprint ridges, to determine a match with a database of reference fingerprints.

Unfortunately, optical sensing may be affected by stained fingers or an optical sensor may be deceived by presentation of a photograph or printed image of a fingerprint rather than a true live fingerprint. In addition, optical schemes may require relatively large spacings between the finger contact surface and associated imaging components. Moreover, such sensors typically require precise alignment and complex scanning of optical beams.

The specification of U.S. Patent No. 4,353,056 discloses another approach to sensing a live fingerprint. In particular, the patent discloses an array of extremely small capacitors located in a plane parallel to the sensing surface of the device. When a finger touches the sensing surface and deforms the surface, a voltage distribution in a series connection of the capacitors may change. The voltages on each of the capacitors is determined by multiplexor techniques.

The specification to U.S. Patent No. 5,325,442 discloses a fingerprint sensor including a plurality of sensing electrodes. Active addressing of the sensing electrodes is made possible by the provision of a switching device associated with each sensing electrode. A capacitor is effectively formed by each sensing electrode in combination with the respective overlying

portion of the finger surface which, in turn, is at ground potential. The sensor may be fabricated using semiconductor wafer and integrated circuit technology. The dielectric material upon which the finger is placed may be provided by silicon nitride or a polyimide which may be provided as a continuous layer over an array of sensing electrodes.

5       Unfortunately, driving the array of closely spaced sensing electrodes may be difficult since adjacent electrodes may affect one another. Another difficulty with such a sensor may be its ability to distinguish ridges and valleys of a fingerprint when the conductivity of the skin and any contaminants may vary widely from person-to-person and even over a single fingerprint. Yet another difficulty with such a sensor, as with many optical sensors, is that different portions  
10 of the fingerprint may require relatively complicated post image collection processing to provide for usable signal levels and contrast to thereby permit accurate determination of the ridges and valleys of the fingerprint. The specification of U.S. Patent No. 4,811,414 discloses methods for noise averaging, illumination equalizing, directional filtering, curvature correcting, and scale correcting for an optically generated fingerprint image.

15       The present invention includes a fingerprint sensor comprising, an array of fingerprint sensing elements, a plurality of active circuits with each active circuit connected to a respective fingerprint sensing element, a plurality of impedance elements connected to said active circuits so that a respective impedance element is selectably connectable between each active circuit for a respective fingerprint sensing element and at least one other active circuit for at least one other  
20 respective adjacent fingerprint sensing element to generate signals relating to a fingerprint, a plurality of switches, with each switch connected in series with a respective impedance element and filter control means for controlling said plurality of switches to filter signals from said active circuits.

      The invention also includes a method for making a fingerprint sensor comprising the  
25 steps of forming an array of fingerprint sensing elements and associated active circuits, forming a plurality of impedance elements connected to the active circuits so that a respective impedance element is selectably connectable between each active circuit for a respective fingerprint sensing element and at least one other active circuit for at least one other respective adjacent fingerprint sensing element to generate signals relating to a fingerprint, further comprising the step of  
30 forming a plurality of switches with a respective switch connected in series with each impedance element, in which the step of forming the plurality of impedance elements comprises forming same with a respective impedance element connectable between each fingerprint sensing

element and eight respective adjacent fingerprint sensing elements, and the step of forming the plurality of impedance elements comprises forming a plurality of resistors.

An object of the invention and the advantages are provided by a fingerprint sensor comprising an array of fingerprint sensing elements and associated active circuits for generating  
5 signals relating to the fingerprint image, and impedance matrix filtering means connected to the active circuits for filtering the signals. The impedance matrix filtering means preferably comprises a plurality of impedance elements with a respective impedance element connectable between each active circuit of a respective fingerprint sensing element and at least one other active circuit for a respective at least one adjacent fingerprint sensing element. The impedance  
10 matrix filtering means may also include a plurality of switches with a respective switch connected in series with each impedance element. Filter control means may operate the switches to perform processing of the signals generated by the active circuits. In one embodiment, the fingerprint sensing elements may be electric field sensing electrodes, and the active circuits may be amplifiers.

15 Ridge flow determining means may be provided for selectively operating the switches to determine ridge flow directions of the fingerprint image. More particularly, the ridge flow determining means may selectively operate the switches for determining signal strength vectors relating to ridge flow directions of the fingerprint image. In addition, the sensor may include core location determining means cooperating with the ridge flow determining means for  
20 determining a core location of the fingerprint image.

Conveniently, binarizing filter means may be provided for selectively operating the switches to convert a gray scale fingerprint image to a binarized fingerprint image. Considered another way, the impedance matrix may be used to provide dynamic image contrast enhancement. Edge smoothing may also be implemented using the impedance matrix. Other  
25 spatial filters may also be implemented for selectively operating the switches to spatially filter the fingerprint image. Accordingly, processing of the fingerprint image may be carried out at the sensor and thereby reduce additional downstream computational requirements.

The impedance matrix filtering means may comprise a plurality of impedance elements with a respective impedance element connectable between each active circuit for a given  
30 fingerprint sensing element and eight other active circuits for respective adjacent fingerprint sensing elements. The impedance elements may be resistors or capacitors, for example.

Suitably, the provision of control means for sequentially powering sets of active circuits to thereby conserve power and perform filtering. In other words, the respective impedance

elements may also be sequentially connected to perform the filtering function. The power control means may further comprise adaptive means for changing a number of active circuits in a set of active circuits being powered. In addition, the power control means may further comprise means for powering only predetermined ones of the active circuits in a set of active  
5 circuits defined by respective fingerprint sensing elements in the predetermined area to thereby further conserve power while performing filtering. Reader control means may be provided to read only predetermined subsets of each set of active circuits so that a contribution from adjacent active circuits is used for filtering, but other portions are not unnecessarily powered.

One method of the invention is for making a fingerprint sensor. The method comprises  
10 the steps of: forming an array of fingerprint sensing elements and associated active circuits, and forming a plurality of impedance elements so that a respective impedance element is selectably connectable between each active circuit for a respective fingerprint sensing element and at least one other active circuit for at least one other respective adjacent fingerprint sensing element to generate signals relating to a fingerprint.

15 Another method is for sensing a fingerprint image using a sensor of a type comprising a plurality fingerprint sensing elements and associated active circuits, and an impedance matrix filter connected to the active circuits. This method preferably comprises the steps of: generating fingerprint image signals from the active circuits, and determining ridge flow directions in the fingerprint using the impedance matrix filter. The method may also further include the step of  
20 determining a core location of the fingerprint image based on the ridge flow directions.

Yet another method aspect of the invention is for sensing a fingerprint image using a sensor as described above. This method preferably comprises the steps of: generating fingerprint image signals from the active circuits; and converting a gray scale fingerprint image to a binarized fingerprint image using the impedance matrix filter.

25 The invention will now be disclosed, by way of example, with reference to the accompanying drawings in which:

FIG. 1 is a top plan view of a fingerprint sensor.

FIG. 2 is a schematic view of a circuit portion of the fingerprint sensor as shown in FIG.  
1.

30 FIG. 3 is a greatly enlarged top plan view of the sensing portion of the fingerprint sensor as shown in FIG. 1.

FIG. 4 is a schematic diagram of another circuit portion of the fingerprint sensor as shown in FIG. 1.

FIG. 5 is a greatly enlarged side cross-sectional view of a portion of the fingerprint sensor as shown in FIG. 1.

FIG. 6 is a greatly enlarged side cross-sectional view of a portion of an alternate embodiment of the fingerprint sensor.

5 FIG. 7 is a greatly enlarged side cross-sectional view of another portion of the fingerprint sensor as shown in FIG. 1.

FIG. 8 is a schematic block diagram of yet another circuit portion of the fingerprint sensor as shown in FIG. 1.

FIG. 9 is a schematic circuit diagram of a portion of the circuit as shown in FIG. 8.

10 FIG. 10 is a schematic block diagram of still another circuit portion of the fingerprint sensor as shown in FIG. 1.

FIG. 11 is a schematic block diagram of an alternate embodiment of the circuit portion shown in FIG. 10.

FIG. 12 is a schematic block diagram of an additional circuit portion of the fingerprint  
15 sensor as shown in FIG. 1.

FIG. 13 is a schematic block diagram of an alternate embodiment of the circuit portion shown in FIG. 12.

Referring to FIGS. 1-3, the fingerprint sensor 30 includes a housing or package 51, a dielectric layer 52 exposed on an upper surface of the package which provides a placement  
20 surface for the finger, and a plurality of output pins, not shown. A first conductive strip or external electrode 54 around the periphery of the dielectric layer 52, and a second external electrode 53 provide contact electrodes for the finger 79 as described in greater detail below. The sensor 30 may provide output signals in a range of sophistication levels depending on the level of processing incorporated in the package.

25 The sensor 30 includes a plurality of individual pixels or sensing elements 30a arranged in array pattern as perhaps best shown in FIG. 3. These sensing elements are relatively small so as to be capable of sensing the ridges 59 and intervening valleys 60 of a typical fingerprint. Live fingerprint readings as from the electric field sensor 30 in accordance with the present invention may be more reliable than optical sensing, because the impedance of the skin of a finger in a  
30 pattern of ridges and valleys is extremely difficult to simulate. In contrast, an optical sensor may be deceived by a readily deceived by a photograph or other similar image of a fingerprint, for example.

The sensor 30 includes a substrate 65, and one or more active semiconductor devices formed thereon, such as the schematically illustrated amplifier 73. A first metal layer 66 interconnects the active semiconductor devices. A second or ground plane electrode layer 68 is above the first metal layer 66 and separated therefrom by an insulating layer 67. A third metal layer 71 is positioned over another dielectric layer 70. In the illustrated embodiment, the first external electrode 54 is connected to an excitation drive amplifier 74 which, in turn, drives the finger 79 with a signal may be typically in the range of about 1 KHz to 1 MHz. Accordingly, the drive or excitation electronics are thus relatively uncomplicated and the overall cost of the sensor 30 may be relatively low, while the reliability is great.

10      Circularly shaped electric field sensing electrode 78 is on the insulating layer 70. The sensing electrode 78 may be connected to sensing integrated electronics, such as the illustrated amplifier 73 formed adjacent the substrate 65 as schematically illustrated.

    An annularly shaped shield electrode 80 surrounds the sensing electrode 78 in spaced relation therefrom. The sensing electrode 78 and its surrounding shield electrode 80 may have 15 other shapes, such as hexagonal, for example, to facilitate a close packed arrangement or array of pixels or sensing elements 30a. The shield electrode 80 is an active shield which is driven by a portion of the output of the amplifier 73 to help focus the electric field energy and, moreover, to thereby reduce the need to drive adjacent electric field sensing electrodes 78.

    The sensor 30 includes only three metal or electrically conductive layers 66, 68 and 71. 20 The sensor 30 can be made without requiring additional metal layers which would otherwise increase the manufacturing cost, and, perhaps, reduce yields. Accordingly, the sensor 30 is less expensive and may be more rugged and reliable than a sensor including four or more metal layers.

    The amplifier 73 is operated at a gain of greater than about one to drive the shield 25 electrode 80. Stability problems do not adversely affect the operation of the amplifier 73. Moreover, the common mode and general noise rejection are greatly enhanced according to this feature of the invention. In addition, the gain greater than one tends to focus the electric field with respect to the sensing electrode 78.

    The sensing elements 30a operate at very low currents and at very high impedances. For 30 example, the output signal from each sensing electrode 78 is desirably about 5 to 10 millivolts to reduce the effects of noise and permit further processing of the signals. The approximate diameter of each sensing element 30a, as defined by the outer dimensions of the shield electrode 80, may be about 0.002 to 0.005 inches in diameter. The ground plane electrode 68 protects the



active electronic devices from unwanted excitation. The various signal feedthrough conductors for the electrodes 78, 80 to the active electronic circuitry may be readily formed.

The overall contact or sensing surface for the sensor 30 may desirably be about 0.5 by 0.5 inches – a size which may be readily manufactured and still provide a sufficiently large surface  
5 for accurate fingerprint sensing and identification. The sensor 30 in accordance with the invention is also fairly tolerant of dead pixels or sensing elements 30a. A typical sensor 30 includes an array of about 256 by 256 pixels or sensor elements, although other array sizes are also contemplated by the present invention. The sensor 30 may also be fabricated at one time using primarily conventional semiconductor manufacturing techniques to thereby significantly  
10 reduce the manufacturing costs.

Turning now additionally to FIG. 4, another aspect of the sensor 30 is described. The sensor may include power control means for controlling operation of active circuit portions 100 based upon sensing finger contact with the first external electrode 54 as determined by the illustrated finger sense block or circuit 101. For example, the finger sense circuit 101 may operate  
15 based upon a change in impedance to an oscillator to thereby determine finger contact. Of course, other approaches for sensing contact with the finger are also contemplated by the invention. The power control means may include wake-up means for only powering active circuit portions upon sensing finger contact with the first external electrode to thereby conserve power. Alternately or additionally, the power control means may further comprise protection  
20 means for grounding active circuit portions upon not sensing finger contact with the first external electrode. In the illustrated embodiment, a combination of wake-up and protection controller circuits 101 are illustrated.

The fingerprint sensor 30 may further comprise finger charge bleed means for bleeding a charge from a finger or other object upon contact therewith. The finger charge bleed means  
25 may be provided by the second external electrode 53 carried by the package 51 for contact by a finger, and a charge bleed resistor 104 connected between the second external electrode and an earth ground. As schematically illustrated in the upper right hand portion of FIG. 4, the second electrode may alternately be provided by a movable electrically conductive cover 53' slidably connected to the package 51 for covering the opening to the exposed upper dielectric layer 52.  
30 A pivotally connected cover is also contemplated by the present invention. Accordingly, under normal conditions, the charge would be bled from the finger as the cover 53' is moved to expose the sensing portion of the sensor 30.

The finger charge bleed means and power control means may be such that the active portions remain grounded until the charge bleed means can remove the charge on the finger before powering the active circuit portions, such as by providing a brief delay during wake-up sufficient to permit the charge to be discharged through the resistor 104. Accordingly, power  
5 may be conserved in the sensor 30 and ESD protection provided by the sensor so that the sensor is relatively inexpensive, yet robust and conserves power.

Referring to FIG. 5 another significant feature of the sensor 30 is described. The dielectric covering 52 may preferably comprise a z-axis anisotropic dielectric layer 110 for focussing an electric field, shown by the illustrated field lines, at each of the electric field sensing electrodes  
10 78. In other words, the dielectric layer 110 may be relatively thick, but not result in defocussing of the electric fields propagating therethrough because of the z-axis anisotropy of the material. Typically there would be a trade-off between field focus and mechanical protection. Unfortunately, a thin film which is desirable for focussing, may permit the underlying circuit to be more easily subject to damage.

15 The z-axis anisotropic dielectric layer 110 of the present invention, for example, may have a thickness in range of about 0.0001 to 0.004 inches. Of course, the z-axis anisotropic dielectric layer 110 is also preferably chemically resistant and mechanically strong to withstand contact with fingers, and to permit periodic cleanings with solvents. The z-axis anisotropic dielectric layer 110 may preferably define an outermost protective surface for the integrated circuit die 120.  
20 Accordingly, the overall dielectric covering 52 may further include at least one relatively thin oxide, nitride, carbide, or diamond layer 111 on the integrated circuit die 120 and beneath the z-axis anisotropic dielectric layer 110. The thin layer 111 will typically be relatively hard, and the z-axis anisotropic dielectric layer 110 is desirably softer to thereby absorb more mechanical activity.

25 The z-axis anisotropic dielectric layer 110 may be provided by a plurality of oriented dielectric particles in a cured matrix. For example, the z-axis anisotropic dielectric layer 110 may comprise barium titanate in a polyimide matrix.

Turning to FIG. 6, another variation of a z-axis dielectric covering 52' is schematically shown by a plurality of high dielectric portions 112 aligned with corresponding electric field  
30 sensing electrodes 78, and a surrounding matrix of lower dielectric portions 113. This embodiment of the dielectric covering 52' may be formed in a number of ways, such as by forming a layer of either the high dielectric or low dielectric portions, selectively etching same, and filling the openings with the opposite material. Another approach may be to use polarizable

microcapsules and subjecting same to an electric field during curing of a matrix material. A material may be compressed to cause the z-axis anisotropy.

Another aspect of the invention relates to being able to completely cover and protect the entire upper surface of the integrated circuit die 120, and still permit connection and communication with the external devices and circuits as now further explained with reference to FIG. 7. The third metal layer 71 (FIG. 2) preferably further includes a plurality of capacitive coupling pads 116a-118a for permitting capacitive coupling of the integrated circuit die 120. Accordingly, the dielectric covering 52 is preferably continuous over the capacitive coupling pads 116a-118a and the array of electric field sensing electrodes 78 of the pixels 30a (FIG. 1). In sharp contrast to this feature of the present invention, it is conventional to create openings through an outer coating to electrically connect to the bond pads. Unfortunately, these openings would provide pathways for water and/or other contaminants to come in contact with and damage the die.

A portion of the package 51 includes a printed circuit board 122 which carries corresponding pads 115b-118b. A power modulation circuit 124 is coupled to pads 115b-116b, while a signal modulation circuit 126 is illustrative coupled to pads 117b-118b. Both power and signals may be readily coupled between the printed circuit board 122 and the integrated circuit die 120, further using the illustrated power demodulation/regulator circuit 127, and the signal demodulation circuit 128. The z-axis anisotropic dielectric layer 110 also advantageously reduces cross-talk between adjacent capacitive coupling pads. This embodiment of the invention presents no penetrations through the dielectric covering 52 for moisture to enter and damage the integrated circuit die 120. In addition, another level of insulation is provided between the integrated circuit and the external environment.

For the illustrated fingerprint sensor 30, the package 51 preferably has an opening aligned with the array of electric field sensing electrodes 78 (FIGS. 1-3). The capacitive coupling and z-axis anisotropic layer 110 may be advantageously used in a number of applications in addition to the illustrated fingerprint sensor 30, and particularly where it is desired to have a continuous film covering the upper surface of the integrated circuit die 120 and pads 116a-118a.

Referring to FIGS. 8 and 9, impedance matrix filtering aspects of the invention are now described. As shown in FIG. 8, the fingerprint sensor 30 may be considered as comprising an array of fingerprint sensing elements 130 and associated active circuits 131 for generating signals relating to the fingerprint image. The illustrated sensor 30 also includes an impedance matrix 135 connected to the active circuits for filtering the signals therefrom.

As shown in FIG. 9, the impedance matrix 135 includes a plurality of impedance elements 136 with a respective impedance element connectable between each active circuit of a respective fingerprint sensing element as indicated by the central node 138, and the other active circuits (outer nodes 140). The impedance matrix 135 also includes a plurality of switches 137 with a  
5 respective switch connected in series with each impedance element 136. An input signal may be supplied to the central node 138 via the illustrated switch 142 and its associated impedance element 143. The impedance element may one or more of a resistor as illustrated, and a capacitor 134.

Filter control means may operate the switches 137 to perform processing of the signals  
10 generated by the active circuits 131. In one embodiment, the fingerprint sensing elements 130 may be electric field sensing electrodes 78, and the active circuits 131 may be amplifiers 73 (FIG. 2). Of course other sensing elements and active circuits may also benefit from the impedance matrix filtering of the present invention.

Ridge flow determining means 145 may be provided for selectively operating the  
15 switches 137 of the matrix 135 to determine ridge flow directions of the fingerprint image. More particularly, the ridge flow determining means 145 may selectively operate the switches 137 for determining signal strength vectors relating to ridge flow directions of the fingerprint image. The ridge flow directions may be determined based upon well known rotating slit principles.

The sensor 30 may include core location determining means 146 cooperating with the  
20 ridge flow determining means 145 for determining a core location of the fingerprint image. The position of the core is helpful, for example, in extracting and processing minutiae from the fingerprint image.

As illustrated in FIG. 8, a binarizing filter 150 may be provided for selectively operating the switches 137 to convert a gray scale fingerprint image to a binarized fingerprint image.  
25 Considered another way, the impedance matrix 135 may be used to provide dynamic image contrast enhancement. In addition, an edge smoothing filter 155 may be readily implemented to improve the image. As also schematically illustrated other spatial filters 152 may also be implemented using the impedance matrix 135 for selectively operating the switches 137 to spatially filter the fingerprint image as would be readily appreciated by those of skill in the art.  
30 Accordingly, processing of the fingerprint image may be carried out at the sensor 30 and thereby reduce additional downstream computational requirements.

The embodiment of FIG. 9 shows the impedance matrix 135 may comprise a plurality of impedance elements with a respective impedance element 136 connectable between each active

circuit for a given fingerprint sensing element 130 and eight other active circuits for respective adjacent fingerprint sensing elements.

A control means 153 for sequentially powering sets of active circuits 131 to conserve power. Of course, the respective impedance elements 136 are desirably also sequentially  
5 connected to perform the filtering function. The powered active circuits 131 may be considered as defining a cloud or kernel. The power control means 153 may be operated in an adaptive fashion whereby the size of the area used for filtering is dynamically changed for preferred image characteristics. In addition, the power control means 153 may also power only certain ones of the active circuits corresponding to a predetermined area of the array of sensing elements  
10 130. For example, every other active circuit 131 could be powered to thereby provide a larger area, but reduced power consumption.

Reader control means 154 may be provided to read only predetermined subsets of each set of active circuits 131 so that a contribution from adjacent active circuits is used for filtering. In other words, only a subset of active circuits 131 are typically simultaneously read although  
15 adjacent active circuits 131 and associated impedance elements 136 are also powered and connected, respectively. For example, 16 impedance elements 136 could define a subset and be readily simultaneously read. The subset size could be optimized for different sized features to be determined.

Accordingly, the array of sense elements 130 can be quickly read, and power  
20 consumption substantially reduced since all of the active circuits 131 need not be powered for reading a given set of active circuits. For a typical sensor, the combination of the power control and impedance matrix features described herein may permit power savings by a factor of about 10 as compared to powering the full array.

It is another important advantage of the fingerprint sensor 30 according to present  
25 invention to guard against spoofing or deception of the sensor into incorrectly treating a simulated image as a live fingerprint image. For example, optical sensors may be deceived or spoofed by using a paper with a fingerprint image thereon. The unique electric field sensing of the fingerprint sensor 30 of the present invention provides an effective approach to avoiding spoofing based upon the complex impedance of a finger.

30 As shown in FIG. 10, the fingerprint sensor 30 may be considered as including an array of impedance sensing elements 160 for generating signals related to a finger 79 or other object positioned adjacent thereto. In the embodiment described herein, the impedance sensing elements 160 are provided by electric field sensing electrodes 78 and amplifiers 73 (FIG. 2)

associated therewith. In addition, a guard shield 80 may be associated with each electric field sensing electrode 78 and connected to a respective amplifier 73. Spoof reducing means 161 is provided for determining whether or not an impedance of the object positioned adjacent the array of impedance sensing elements 160 corresponds to a live finger 79 to thereby reduce spoofing of the fingerprint sensor by an object other than a live finger. A spoofing may be indicated, such as by the schematically illustrated lamp 163 and/or used to block further processing. Alternately, a live fingerprint determination may also be indicated by a lamp 164 and/or used to permit further processing of the fingerprint image.

In one embodiment, the spoof reducing means 161 may include impedance determining means 165 to detect a complex impedance having a phase angle in a range of about 10 to 60 degrees corresponding to a live finger 79. Alternately, the spoof reducing means 161 may detect an impedance having a phase angle of about 0 degrees corresponding to some objects other than a live finger, such as a sheet of paper having an image thereon, for example. In addition, the spoof reducing means 161 may detect an impedance of 90 degrees corresponding to other objects.

Turning now to FIG. 11, another embodiment of spoof reducing means is explained. The fingerprint sensor 30 may preferably includes drive means for driving the array of impedance sensing elements 160, such as the illustrated excitation amplifier 74 (FIG. 2). The sensor also includes synchronous demodulator means 170 for synchronously demodulating signals from the array of impedance sensing elements 160. Accordingly, in one particularly advantageous embodiment of the invention, the spoof reducing means comprises means for operating the synchronous demodulator means 170 at at least one predetermined phase rotation angle. For example, the synchronous demodulator means 170 could be operated in a range of about 10 to 60 degrees, and the magnitude compared to a predetermined threshold indicative of a live fingerprint. A live fingerprint typically has a complex impedance within the range of 10 to 60 degrees.

Alternately, ratio generating and comparing means 172 may be provided for cooperating with the synchronous demodulator means 170 for synchronously demodulating signals at first and second phase angles  $\theta_1$ ,  $\theta_2$ , generating an amplitude ratio thereof, and comparing the amplitude ratio to a predetermined threshold to determine whether the object is a live fingerprint or other object. Accordingly, the synchronous demodulator 170 may be readily used to generate the impedance information desired for reducing spoofing of the sensor 30 by an

object other than a live finger. The first angle  $\theta_1$  and the second  $\theta_2$  may have a difference in a range of about 45 to 90 degrees, for example.

The fingerprint sensor 30 also includes an automatic gain control feature to account for a difference in intensity of the image signals generated by different fingers or under different  
5 conditions, and also to account for differences in sensor caused by process variations. It is important for accurately producing a fingerprint image, that the sensor can discriminate between the ridges and valleys of the fingerprint. Accordingly, the sensor 30 includes a gain control feature, a first embodiment of which is understood with reference to FIG. 12.

As shown in FIG. 12, the illustrated portion of the fingerprint sensor 30 includes an array  
10 of fingerprint sensing elements in the form of the electric field sensing electrodes 78 and surrounding shield electrodes 80 connected to the amplifiers 73. Other fingerprint sensing elements may also benefit from the following automatic gain control implementations.

The signal processing circuitry of the sensor 30 preferably includes a plurality of analog-to-digital (A/D) converters 180 as illustrated. Moreover, each of these A/D converters 180 may  
15 have a controllable scale. Scanning means 182 sequentially connects different elements to the bank of A/D converters 180. The illustrated gain processor 185 provides range determining and setting means for controlling the range of the A/D converters 180 based upon prior A/D conversions to thereby provide enhanced conversion resolution. The A/D converters 180 may comprise the illustrated reference voltage input  $V_{ref}$  and offset voltage input  $V_{offset}$  for permitting  
20 setting of the range as would be readily appreciated by those skilled in the art. Accordingly, the range determining and setting means may also comprise a first digital-to-analog D/A converter 186 connected between the gain processor 185 and the reference voltage  $V_{ref}$  inputs of the A/D converters 180. In addition, a second D/A converter 189 is also illustratively connected to the offset voltage inputs  $V_{offset}$  from the gain processor 185.

25 The gain processor 185 may comprise histogram generating means for generating a histogram, as described above, and based upon prior A/D conversions. The graph adjacent the gain processor 185 in FIG. 12 illustrates a typical histogram plot 191. The histogram plot 191 includes two peaks corresponding to the sensed ridges and valleys of the fingerprint. By setting the range for the A/D converters 180, the peaks can be readily positioned as desired to  
30 thereby account for the variations discussed above and use the full resolution of the A/D converters 180.

Turning additionally to FIG. 13, the A/D converters 180 may include an associated input amplifier for permitting setting of the range. In this variation, the range determining and setting

means may also comprise the illustrated gain processor 185, and wherein the amplifier is a programmable gain amplifier (PGA) 187 connected to the processor. A digital word output from the gain processor 185 sets the gain of the PGA 187 so that full use of the resolution of the A/D converters 180 is obtained for best accuracy. A second digital word output from the gain  
5 processor 185 and coupled to the amplifier 187 through the illustrated D/A converter 192 may also control the offset of the amplifier .

The range determining and setting means of the gain processor 185 may comprise default setting means for setting a default range for initial ones of the fingerprint sensing elements. The automatic gain control feature of the present invention allows the D/A converters 180 to operate  
10 over their full resolution range to thereby increase the accuracy of the image signal processing.

A fingerprint sensor includes an array of fingerprint sensing elements and associated active circuits and an impedance matrix filter connected to the active circuits for filtering the signals. The impedance matrix filter comprises a plurality of impedance elements with a respective impedance element connectable between each the active circuit for each fingerprint  
15 sensing element and at least one other active circuit for an adjacent fingerprint sensing element. The impedance matrix filter includes a plurality of switches with a respective switch connected in series with each impedance element. The switches are selectively operated to determine ridge flow directions of the fingerprint image. The ridge flow directions are used to determine a core location of the fingerprint image. The switches are selectively operated to convert a gray scale  
20 fingerprint image to a binarized fingerprint image. Processing of the fingerprint image is carried out at the sensor and reduces additional downstream computational requirements.



CLAIMS

1. A fingerprint sensor comprising, an array of fingerprint sensing elements, a plurality of active circuits with each active circuit connected to a respective fingerprint sensing element, a plurality of impedance elements connected to said active circuits so that a respective  
5 impedance element is selectably connectable between each active circuit for a respective fingerprint sensing element and at least one other active circuit for at least one other respective adjacent fingerprint sensing element to generate signals relating to a fingerprint, a plurality of switches, with each switch connected in series with a respective impedance element and filter control means for controlling said plurality of switches to filter signals from said active circuits.
- 10 2. A fingerprint sensor as claimed in claim 1 wherein said filter control means comprises ridge flow determining means for selectively operating said switches to determine ridge flow directions of a fingerprint image, in which said ridge flow determining means comprises means for selectively operating said switches for determining signal strength vectors relating to ridge flow directions of the fingerprint image.
- 15 3. A fingerprint sensor as claimed in claim 2 including core location determining means cooperating with said ridge flow determining means for determining a core location of the fingerprint image, and said filter control means further comprises binarizing filter means for selectively operating said switches to convert a gray scale fingerprint image to a binarized fingerprint image, in which said filter control means comprises edge smoothing filter means for  
20 selectively operating said switches to smooth edges of the fingerprint image.
4. A fingerprint sensor as claimed in any one of claims 1 to 3 wherein said plurality of impedance elements are arranged in a matrix with a respective impedance element selectably connectable between each active circuit for a respective fingerprint sensing element and eight other active circuits for respective eight adjacent fingerprint sensing elements, and each  
25 impedance element comprises at least one of a resistor and a capacitor.
5. A fingerprint sensor as claimed in claim 4 including power control means for sequentially powering a plurality of sets of active circuits and connecting the impedance elements therefor, with each set of active circuits defined by respective fingerprint sensing elements in a corresponding predetermined area in the array of fingerprint sensing elements.
- 30 6. A fingerprint sensor as claimed in claim 5 wherein said power control means comprises adaptive means for changing a number of active circuits in a set of active circuits being powered, said power control means further comprises means for powering only predetermined ones of the active circuits in a set of active circuits defined by respective fingerprint sensing

elements in the predetermined area, in which reader control means for simultaneously reading a plurality of active circuits in each set of active circuits, and said reader control means comprises means for reading a subset of active circuits in each set of active circuits, in which each fingerprint sensing element comprises an electric field sensing electrode; and each active circuit  
5 comprises an amplifier connected to a respective electric field sensing electrode.

7. A fingerprint sensor comprising, an array of fingerprint sensing elements, a plurality of active circuits with each active circuit connected to a respective fingerprint sensing element, control means for sequentially powering a plurality of sets of active circuits, with each set of active circuits defined by respective fingerprint sensing elements in a corresponding  
10 predetermined area in the array of fingerprint sensing elements, and reader control means for reading a plurality of active circuits in each set of active circuits as each set of active circuits is sequentially powered.

8. A fingerprint sensor as claimed in claim 7 wherein said power control means comprises adaptive means for changing a number of active circuits in a set of active circuits being  
15 powered, said power control means further comprises means for powering only predetermined ones of the active circuits in a set of active circuits defined by respective fingerprint sensing elements in the predetermined area, and in which said reader control means comprises means for reading a subset of active circuits in each set of active circuits.

9. A fingerprint sensor as claimed in claim 8 including a plurality of impedance  
20 elements connected to said active circuits so that a respective impedance element is selectably connectable between each active circuit for a respective fingerprint sensing element and at least one other active circuit for at least one other respective adjacent fingerprint sensing element, a plurality of switches, with each switch connected in series with a respective impedance element, filter control means for connecting the respective impedance elements for each set of active  
25 circuits as each is sequentially powered, in which said plurality of impedance elements are arranged in a matrix with a respective impedance element selectably connectable between each active circuit for a respective fingerprint sensing element and eight other active circuits for respective eight adjacent fingerprint sensing elements, each impedance element comprises at least one of a resistor and a capacitor, and in which each fingerprint sensing element comprises  
30 an electric field sensing electrode; and each active circuit comprises an amplifier connected to a respective electric field sensing electrode.

10. A fingerprint sensor comprising an array of fingerprint sensing elements, a plurality of active circuits with each active circuit connected to a respective fingerprint sensing

element, impedance matrix filtering means connected to said plurality of active circuits for filtering signals therefrom, ridge flow determining means cooperating with said impedance matrix filtering means for determining ridge flow directions in the fingerprint, said impedance matrix filtering means comprises a plurality of impedance elements connected to said active  
5 circuits so that a respective impedance element is selectably connectable between each active circuit for a respective fingerprint sensing element and at least one other active circuit for at least one other respective adjacent fingerprint sensing element, a plurality of switches, with each switch connected in series with a respective impedance element, in which said ridge flow determining means comprises means for selectively operating said switches for determining  
10 signal strength vectors relating to ridge flow directions of the fingerprint image, core location determining means cooperating with said ridge flow determining means for determining a core location of the fingerprint image, and said plurality of impedance elements are arranged so that a respective impedance element is connectable between each fingerprint sensing element and eight respective adjacent fingerprint sensing elements.

15 11. A method for making a fingerprint sensor comprising the steps of forming an array of fingerprint sensing elements and associated active circuits, forming a plurality of impedance elements connected to the active circuits so that a respective impedance element is selectably connectable between each active circuit for a respective fingerprint sensing element and at least one other active circuit for at least one other respective adjacent fingerprint sensing  
20 element to generate signals relating to a fingerprint, further comprising the step of forming a plurality of switches with a respective switch connected in series with each impedance element, in which the step of forming the plurality of impedance elements comprises forming same with a respective impedance element connectable between each fingerprint sensing element and eight respective adjacent fingerprint sensing elements, and the step of forming the plurality of  
25 impedance elements comprises forming a plurality of resistors.

12. A method for sensing a fingerprint using a fingerprint sensor of a type comprising an array of fingerprint sensing elements and associated active circuits, the method comprising the steps of:

sequentially powering a plurality of sets of active circuits, with each set of active circuits  
30 defined by respective fingerprint sensing elements in a corresponding predetermined area in the array of fingerprint sensing elements, and reading a plurality of active circuits in each set of active circuits as each set of active circuits is sequentially powered, further comprising the step of changing a number of active circuits in a set of active circuits being sequentially powered, in

which the step of sequentially powering comprises powering only predetermined ones of the active circuits in a set of active circuits defined by respective fingerprint sensing elements in the predetermined area.

13. A method as claimed in claim 12 wherein the step of reading comprises reading  
5 a subset of active circuits in each set of active circuits, and the fingerprint sensor further comprises a plurality of impedance elements connected to the active circuits so that a respective impedance element is selectably connectable between each active circuit for a respective fingerprint sensing element and at least one other active circuit for at least one other respective adjacent fingerprint sensing element, and a plurality of switches, with each switch connected in  
10 series with a respective impedance element; and wherein the method further comprises the step of connecting the respective impedance elements for each set of active circuits as each is sequentially powered.

14. A method for sensing a fingerprint using a fingerprint sensor of a type comprising an array of fingerprint sensing elements and associated active circuits, and an impedance matrix  
15 filter connected to the active circuits, the method comprising the steps of generating fingerprint image signals from the active circuits, and determining ridge flow directions in the fingerprint image signals using the impedance matrix filter, in which the impedance matrix filter comprises a plurality of impedance elements with a respective impedance element connectable between each active circuit for a respective fingerprint sensing element and at least one other active circuit  
20 for a respective at least one adjacent fingerprint sensing element and a plurality of switches with a respective switch connected in series with each impedance element; and the step of determining ridge flow directions comprises selectively operating the switches for determining signal strength vectors relating to ridge flow directions of the fingerprint image.

15. A method as claimed in claim 14 including the step of determining a core location  
25 of the fingerprint image based on the ridge flow directions.

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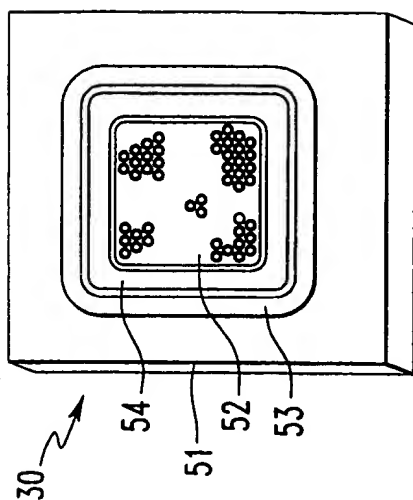


FIG. 1

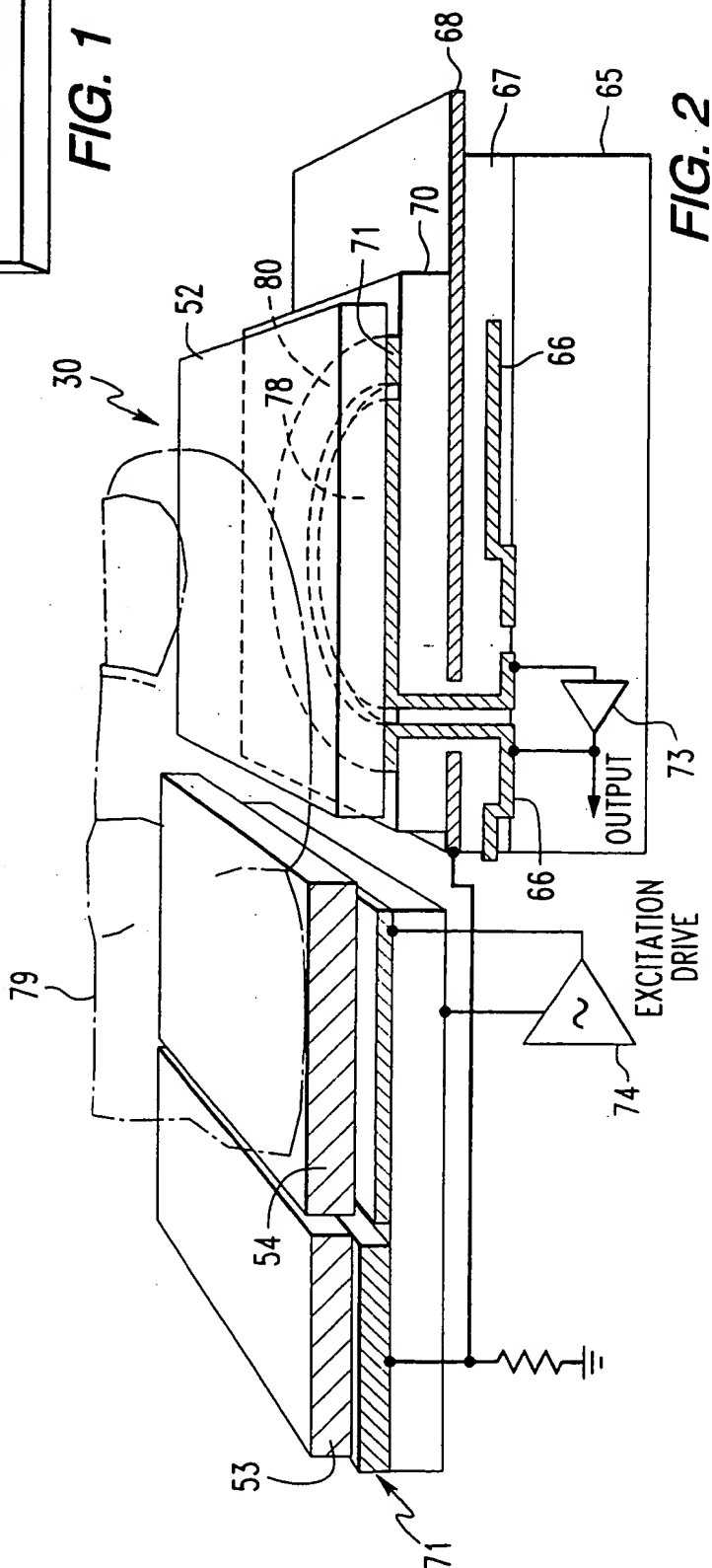


FIG. 2

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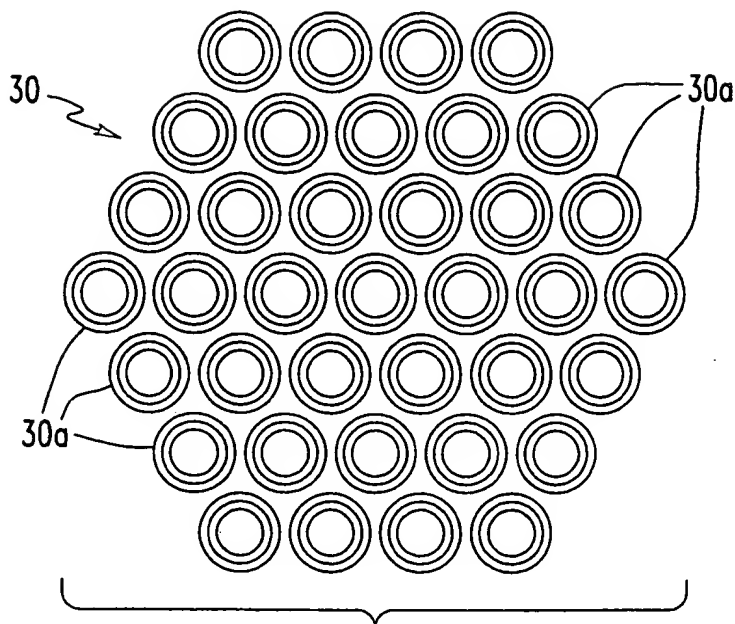


FIG. 3

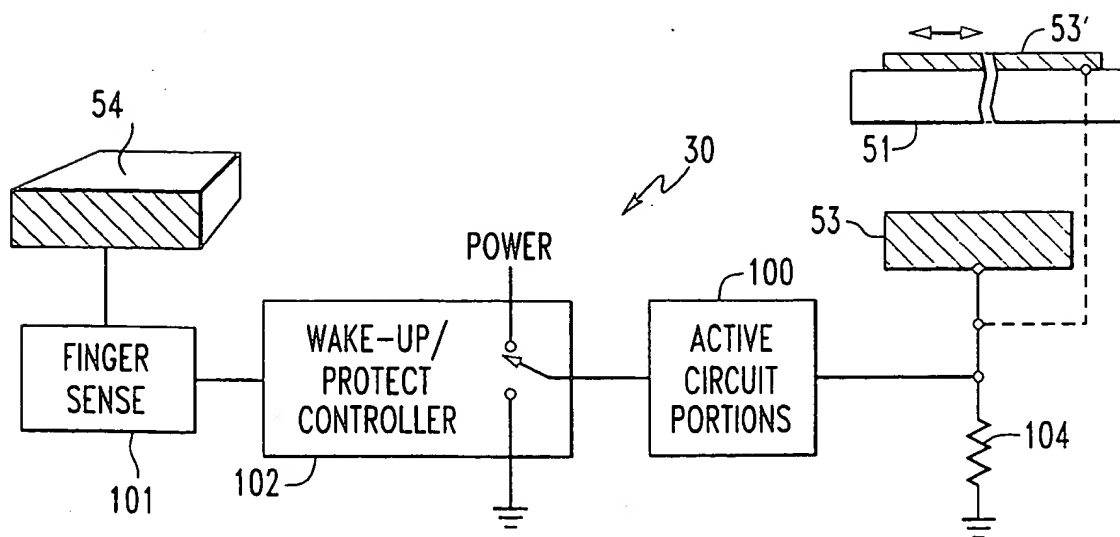


FIG. 4

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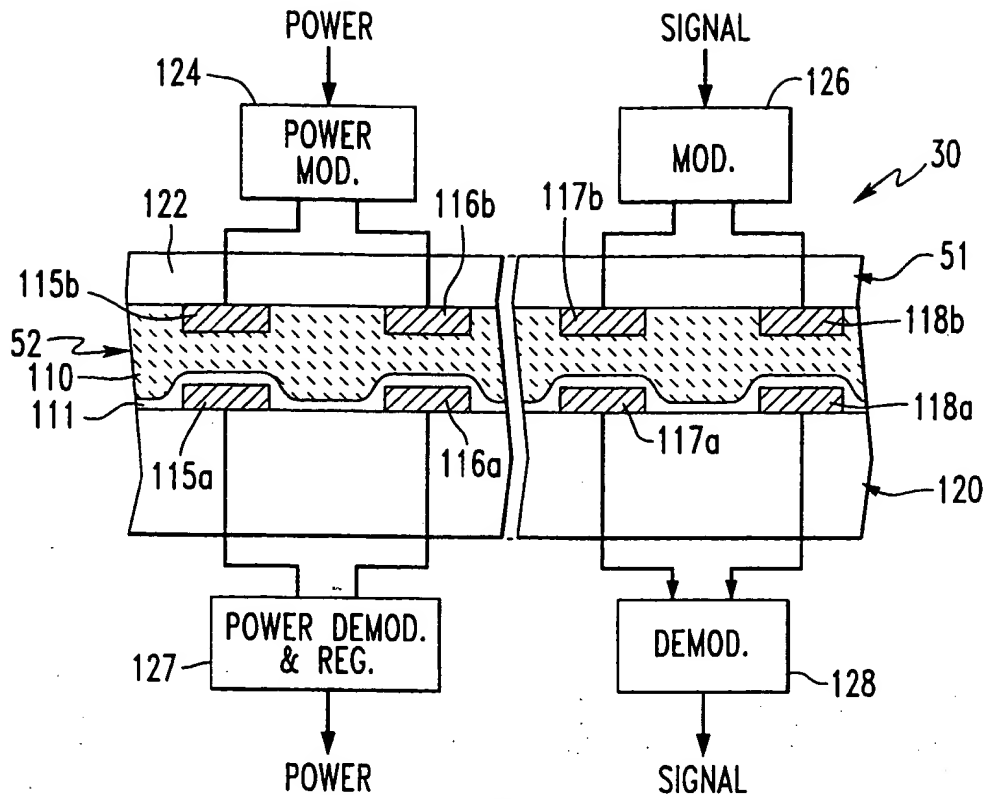


FIG. 7

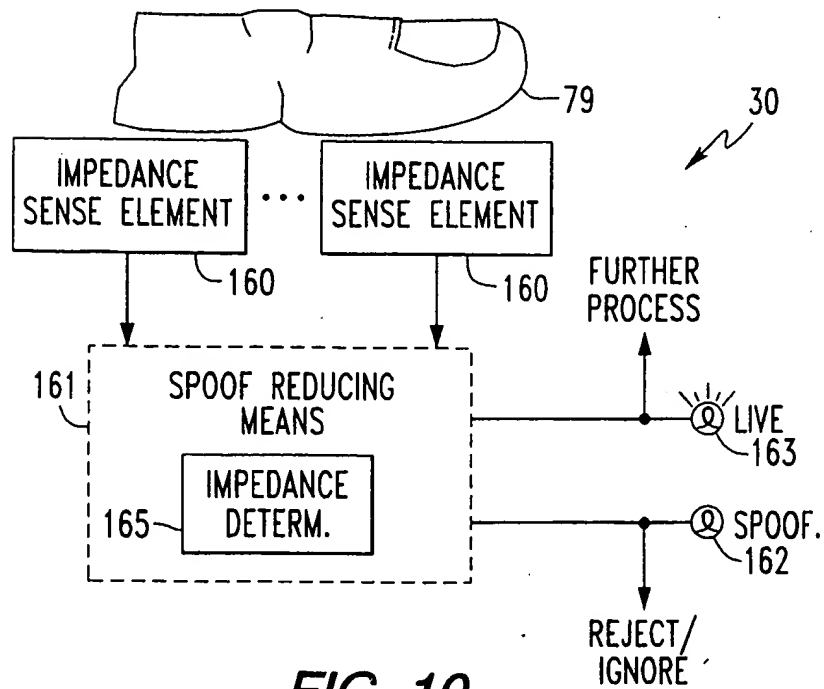


FIG. 10

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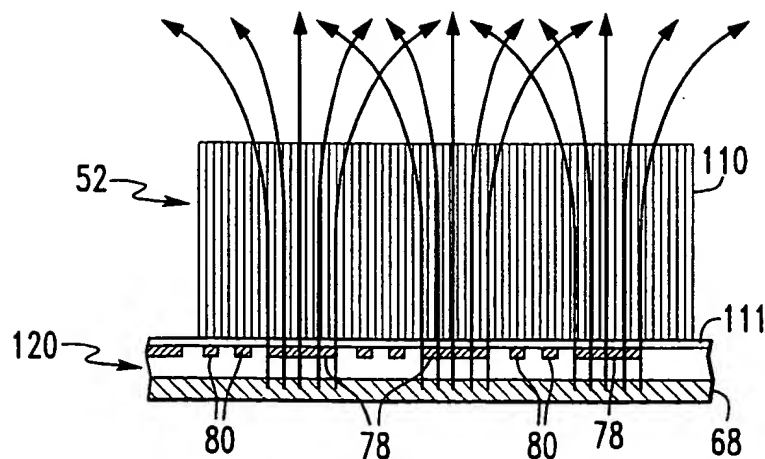


FIG. 5

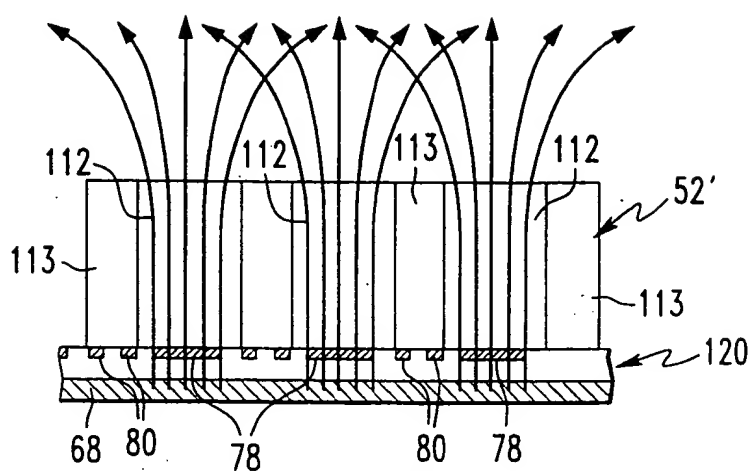


FIG. 6

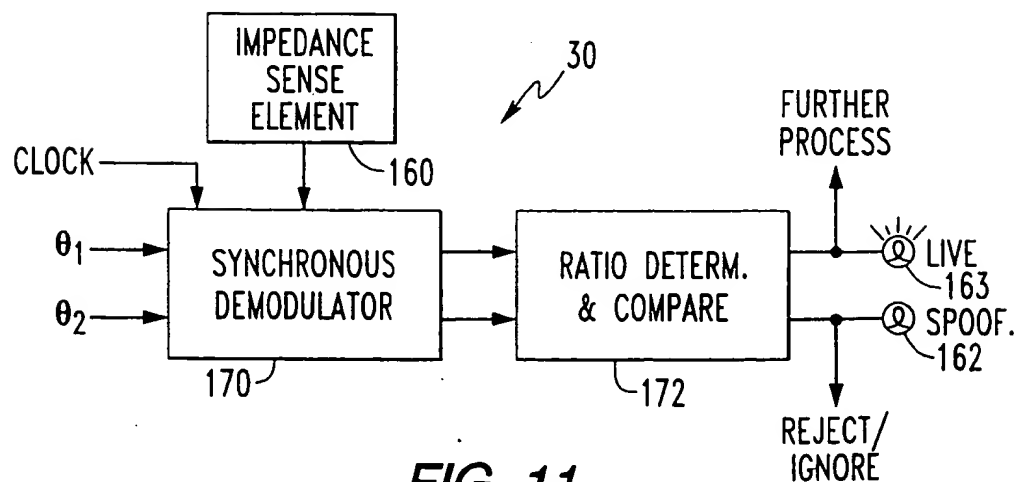


FIG. 11



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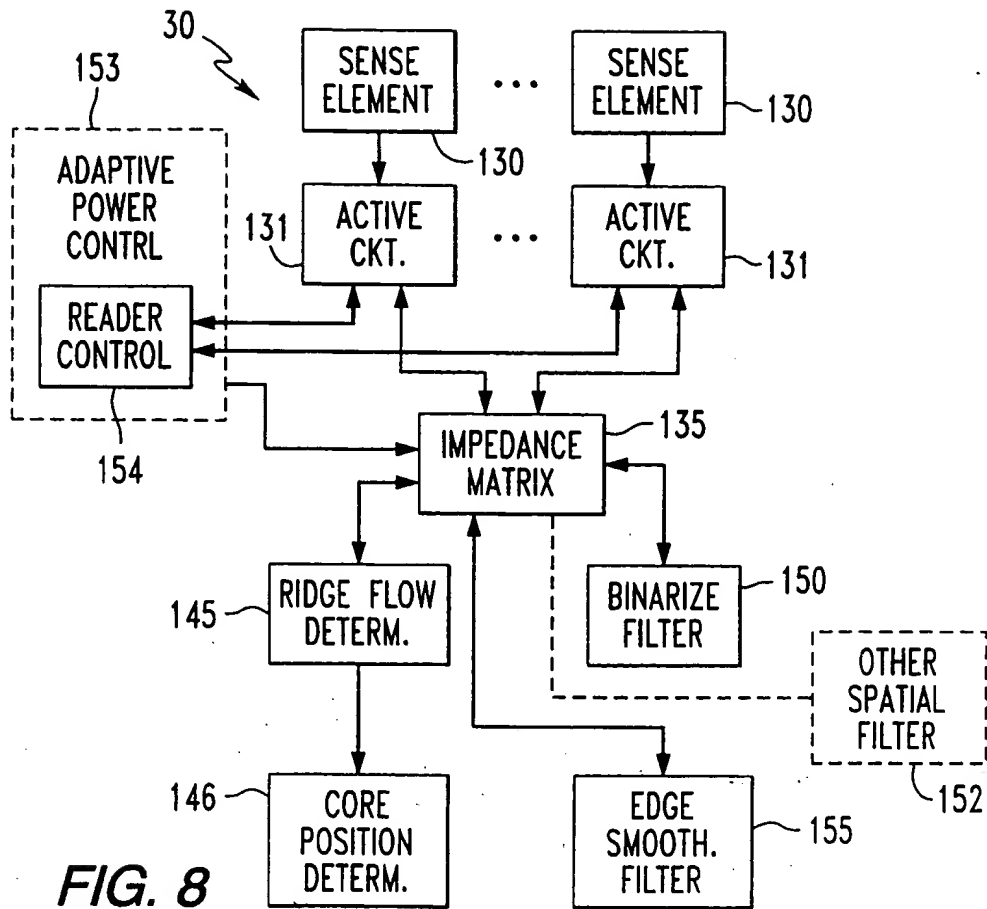


FIG. 8

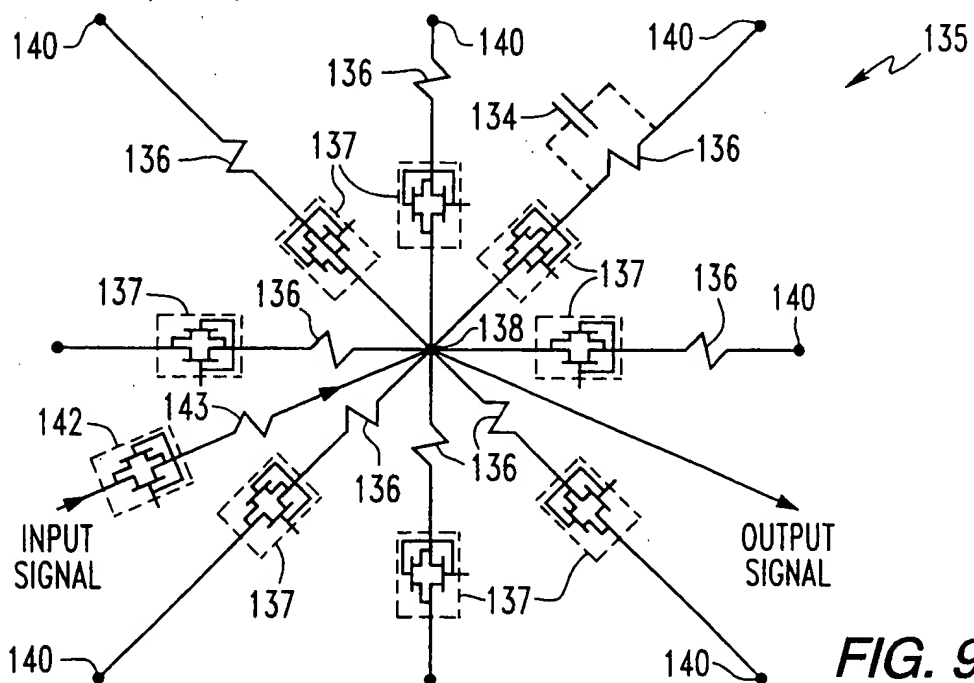


FIG. 9

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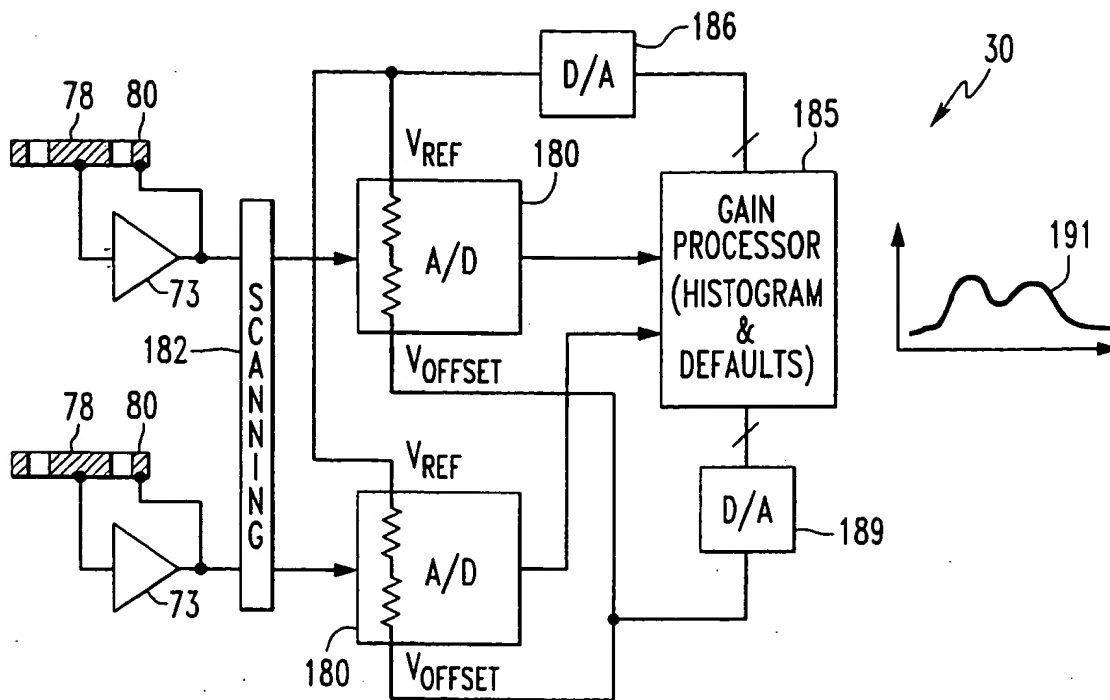


FIG. 12

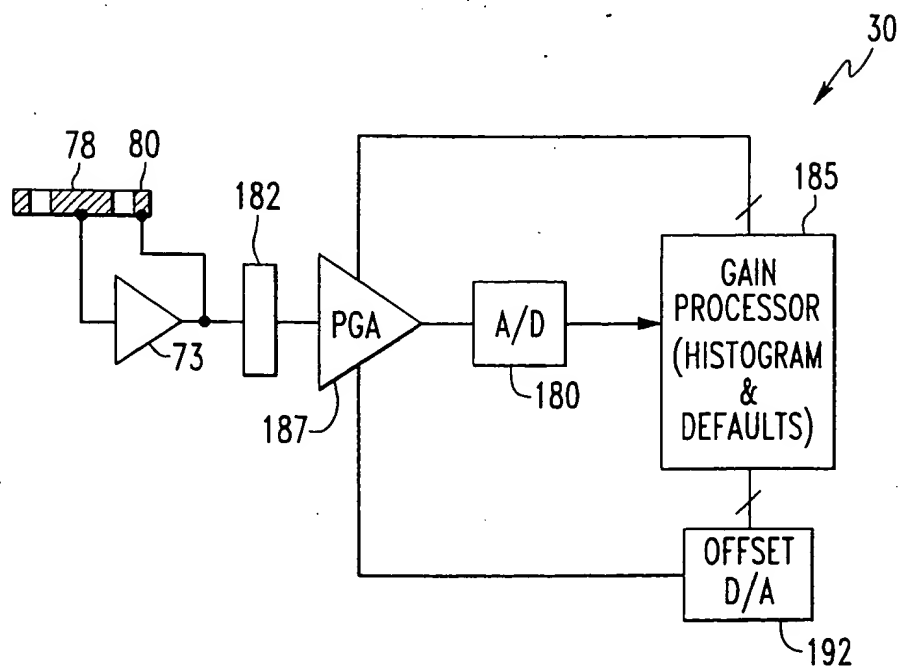


FIG. 13

# INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 98/09228

**A. CLASSIFICATION OF SUBJECT MATTER**  
 IPC 6 G06K9/20 A61B5/117

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 G06K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category * | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|------------|--|-----------------------|
| A          | US 3 781 855 A (KILLEN D) 25 December 1973<br>see abstract                         | 1,7,10,<br>12,14      |
| A          | US 4 547 898 A (TSIKOS CONSTANTINE J) 15<br>October 1985<br>see abstract           | 1,7,<br>10-12,14      |
| A          | US 4 792 982 A (DEVOS FRANCIS ET AL) 20<br>December 1988<br>see abstract           |                       |

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

19 August 1998

Date of mailing of the international search report

27/08/1998

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# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 98/09228

| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member(s)                                    | Publication<br>date                                  |
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DOCKET NO: GR 98P 2516P

SERIAL NO: 09/801,962

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